Bulletin of Electrical Engineering and Informatics
Vol. 11, No. 5, October 2022, pp. 2564~2572
ISSN: 2302-9285, DOI: 10.11591/eei.v11i5.3940

Optimal backstepping controller for controlling DC motor speed

Layla H. Abood[1], Bashra Kadhim Oleiwi[1], Ekbal Hussain Ali[2]
[1]Department of Control and System Engineering, University of Technology, Iraq
[2]Department of Electromechanical Engineering, University of Technology, Iraq

Article Info

Article history:

Received Apr 10, 2022
Revised Jul 12, 2022
Accepted Aug 3, 2022

Keywords:

Backstepping
DC Motor
Optimization
Squirrel search algorithm

ABSTRACT

In this paper, squirrel search algorithm (SSA) is adapted to tune the optimal parameters of a backstepping controller for controlling speed in DC motor; Lyapunov stability theorem is applied to derive the control low to achieve system stability analysis. M-file and Simulink platform is used to simulate the response of the system, a comparison with conventional controllers is utilized, all gains are tuned using SSA method and integral time absolute error (ITAE) fitness function to test the efficient performance of the proposed controller also a comparison with other tuned different controllers is done. Transient response analysis is used to validating the proposed controller performance. The simulation results showed a stable response and efficint performance for the proposed controller when compared with the two conventional controllers used by 41.6% for PID controller and by 32% for PI controller in rise time while in settling time is superior by 36.97% for PID controller and by 41.82% for PI controlle these values led for achieving the desired speed in fast and stable response.

Corresponding Author:

Layla H. Abood
Departement of Control and Systems Engineering, University of Technology
Baghdad, Iraq
Email: 60066@uotechnology.edu.iq

1. INTRODUCTION

Nowadays, DC motors achieves clear spread and prosperity in industrial and commercial markets like robotic manipulators, home appliances, medical devices, vacuum cleaners and electric vehicle industry due to many reasons like there flexibility, efficiency and low cost so due to this it must work in precise and stable response even when nonlinearities and disturbances are cognizable, for this issue conventional control methods like PID control are not suitable to achieve efficient performance [1]-[3]. To avoid drawbacks of conventional control methods the nonlinear control techniques have been used such as, Backstepping control, predictive control, sliding mode control and fuzzy logic control, from these control methods, backstepping control method has achieved an efficient influence as a solution for control of nonlinear systems. The matter here is done by devising the plant into subsystems as a first order system and using Lyapunov relation to reach to the stability of the plant, for obtain the virtual control relation for the subsystem the control low will gained from different parts by solving it gradually step by step then the overall control low for the final subsystem will calculated [4]-[6].

Different control methods have been adopted from many researchers to reach to efficient response, some of them use the conventional controller scheme in two ways either by using it with an optimization method to enhance it response by finding the suitable values for its parameters that give the desired response like in [7] propose the Jaya optimization algorithm (JOA) for obtain best performance then compare results

with particle swarm optimization (PSO), concluded that PSO method in steady state response is best than the JOA and JOA is more efficient in transient response as compared to PSO. In [8] adopts a stochastic fractal search (SFS) method, it depends on concept of Fractal, robustness analysis of suggested SFS/PID controller has been carried out when use different values in electrical resistance and motor torque, in [9] presents an improved weed optimization method based on chaotic theory, the issue of finding optimal controller gains values of a DC motor is done efficiently also robust performance achieved with a simplicity in the design of PID. In [10] optimal I-PD structure is used to enhance responses with minimal overshoot and good regulating time if it is compared with the conventional controller while in [11] a cascade and dual configuration is used by adopt an ANFIS with PID and ANFIS with PD controllers but these configurations have a rapid response, minimum overshoot, efficient dynamics and robustness also stable responses. In [12] TID controller is used and tuned by using Firefly algorithm (FA), TID's structure is a modified PID controller but the change is done in proportional part is which it modified to "$(1/s)^n$" and n is a real value, different performance indices is tested such as ITSE, ISE, ITAE, IAE, the best response appeared clearly in ISE index that show best and efficient results.

The main contribution of the paper is the novel optimization method used (SSA) that have a smart search technique reflected on the backstepping controller behavior with the use of Lyapunov function as a control low to improve the performance of DC motor system to reach to the efficient performance with a high level of robustness to face the external disturbances that may happen.

2. DC MOTOR MODELLING

DC motors are divided into two types depending on the way of excitation either self exited or externally exited, here externally excited type will be used for controlling the speed through controlling the voltage of the armature, the circuit that represents DC motor using the control of armature voltage is shown in Figure 1 and the explanation of its variables will be in Table 1 and for evaluate the transfer function of the mathematical model Kirchhoff's law (KVL) is applied as shown [13]-[15]:

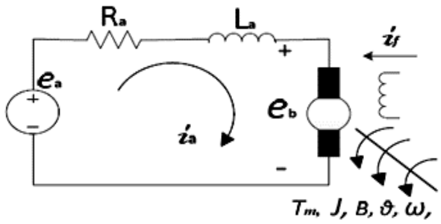

Figure 1. Circuit of DC motor

Table 1. DC motor parameters

Variable	Values
R	1 ohm
L	0.5H
b	0.1 N. M. s
K_b	0.01 vs/rad
K_t	0.01 N.m/A
J	0.01 kg. m^2

$$R_a\, i_a + L_a \frac{di_a}{dt} + e_b = e_a \tag{1}$$

Where R_a *and* L_a are the armature resistance and armature inductance, i_a represents the armature current and e_a and e_b represent the applied voltage and the induced emf in the armature conductors, then e_b is proportional to the motor angular speed w= $\frac{d\theta}{dt}$.

$$e_b = K_b \frac{d\theta}{dt} = K_b\, w \tag{2}$$

K_b is the back emf constant, the torque of the motor is obtained based on newton's low:

$$T = J \frac{dw}{dt} + B\, w = K_t\, i_a \tag{3}$$

K_t is the torque constant, J is the rotor inertia and B is the friction constant. Then by applying Laplace transform to [1]-[3]:

$$E_b(s)= K_b\ w(s) \tag{4}$$

$$E_a(s)=(L_a s + R_a)I_a(s) + E_b(s) \tag{5}$$

$$T(s)=(Js + B)\ w(s) = K_t\ I_a(s) \tag{6}$$

The transfer function will be written as in (7):

$$G(s) = \frac{w(s)}{E_a(s)} = \frac{K_t}{(Ls+R)(Js+B)+ K_b K_t} \tag{7}$$

3. BACKSTEPPING CONTROLLER DESIGN

The backstepping control scheme is a recursive control approach used for achieve stability for highly nonlinear systems by dividing them into first order subsystems with the benefits of using virtual control parameters, to achieve stability for the system a Lyapunov function is used to stabilize the error generating and drive virtual control parameters, the design block diagram explain the DC motor controlled by an optimal backstepping controller and the steps for designing such controller are as shown [16]-[19]. The transfer function for the system rearrange as shown:

$$G(s) = \frac{w(s)}{E_a(s)} = \frac{K_t}{(Ls+R)(Js+B)+ K_b K_t} \tag{8}$$

$$G(s) = \frac{w(s)}{E_a(s)} = \frac{(\frac{K_t}{LJ})}{S^2+\frac{(RJ+BL)}{LJ}S+ (RB+K_b K_t)/LJ} \tag{9}$$

Now for simplify equations let

$$A = \left(\frac{K_t}{LJ}\right), B=\frac{(RJ+BL)}{LJ}, C=\frac{(RJ+BL)}{LJ}$$

then it will be as shown:

$$G(s) = \frac{w(s)}{E_a(s)} = \frac{A}{S^2+BS+ C} \tag{10}$$

and can be written as (let w(s)=e)

$$\ddot{e} + B\dot{e} + Ce = Au \tag{11}$$

$$\ddot{e} = -B\dot{e} - Ce + Au \tag{12}$$

then (12) can be formulated as outlined (13) in a nonlinear dynamic equation:

$$\ddot{x} = F(x) + g(x)u + d(t) \tag{13}$$

Where $F(x)= -B\dot{e} - Ce$, $g(x)=A$, $d(t)$ is the external disturbance.
Now for find the tacking error (z_1) the desired value will be e_d and the actual value of response is e_b then

$$z_1 =e_d - e_b) \tag{14}$$

$$\dot{z_1} = \dot{e_d} - \dot{e_b} \tag{15}$$

The first L yapunov relation is:

$$V_1(z_1) = \frac{1}{2}e^2 \tag{16}$$

and V_1 derivative is:

$$\dot{V_1}(z_1) = z_1 \dot{z_1} = z_1 (\dot{e_d} - \dot{e_b}) \tag{17}$$

$\dot{e_b}$ is considered as a virtual control. A stabilizing function that represents the desired value of the virtual control is expressed as shown:

$$\lambda = \dot{e_d} + k_1 z_1 \tag{18}$$

where k_1 is a constant value tuned by using SSA method, and virtual control is replaced by its desired value then (17) will be:

$$\dot{V_1} = -k_1 {z_1}^2 \le 0 \tag{19}$$

Now the virtual control deviation from desired value is:

$$z_2 = \dot{e_b} - \lambda \tag{20}$$

$$z_2 = \dot{e_b} - \dot{e_d} - k_1 z_1 \tag{21}$$

Now the derivative of z_2 is:

$$\dot{z_2} = \ddot{e_b} - \dot{\lambda} \tag{22}$$

The second Lyapunov function is selected as:

$$V_2(z_1, z_2) = \frac{1}{2}{z_1}^2 + \frac{1}{2}{z_2}^2 \tag{23}$$

and is derivative is

$$\begin{aligned} \dot{V_2}(z_1, z_2) &= z_1 \dot{z_1} + z_2 \dot{z_2} \\ &= z_1 (\dot{e}_d - \dot{e_b}) + z_2 (\ddot{e_b} - \dot{\lambda}) \\ &= z_1 (-z_2 - k_1 z_1) + z_2 (\ddot{e_b} - \ddot{e_d} - k_1 \dot{z_1}) \end{aligned} \tag{24}$$

$$\begin{aligned} &= z_1 (-z_2 - k_1 z_1) + z_2 (\ddot{e_b} - \ddot{e_d} - k_1 \dot{z_1}) \\ &= z_1 (-z_2 - k_1 z_1) + z_2 (\ddot{e_b} - \ddot{e_d} - k_1 \dot{z_1}) \end{aligned} \tag{25}$$

Substitute $\ddot{e_b}$ in (12) and (13) then the equation will be

$$V\dot{V_2}(z_1, z_2) = z_1 (-z_2 - k_1 z_1) + z_2 (F(x) + g(x)u + d(t) - \ddot{e_d} - k_1 \dot{z_1}) \tag{26}$$

$$= -k_1 {z_1}^2 + z_2 (-z_1 + F(x) + g(x)u + d(t) - \ddot{e_d} - k_1 \dot{z_1})) \tag{27}$$

The disturbance signal effect d(t) here is considered as unknown, then for satisfying $\dot{V_2}(z_1, z_2) \le 0$, the system input u(t) will be:

$$u(t) = \frac{1}{g(x)} [z_1 + k_1 \dot{z_1} - F(x) - \ddot{e_d} - k_2 z_2] \tag{28}$$

4. SQUIRREL SEARCH ALGORITHM

The squirrel search algorithm (SSA) was a novel optimization method proposed by Jain *et al.* [20], it assumes that (n) flying squirrels have (n) deciduous trees in the search space, each squirrel have one tree and the manner of searching is done individually, tree types is classified into three (normal, oak or acorn nuts and hickory) and the final assumptions is that three trees is classified as oak tree and one as hickory. The location vector for each ith flying squirrel is defined as follows [21]-[23]:

$$Fs_i = (Fs_{i1}, Fs_{i2}, \dots, Fs_{id}), (i = 1,2, \dots, n) \tag{29}$$

Fs_{ij} is dimension of each flying squirrel and the initial location is:

$$Fs_i = Fs_L + U(0,1) * (Fs_U - Fs_L) \tag{30}$$

Where Fs_U and Fs_L is the upper and lower search bounds and $U(0,1)$ is a random value between [0, 1]. The arrangement of the fitness values for the individuals will be in ascending order, the minimum value for hickory tree, the other three minimum values will be the acorn trees and the rest trees are the normal. The movements of the individuals for finding their food is affected by the predators in the forest, the probability

of predators presence is P_{dp}, if there are no predators in the forest the way of finding food will be classified into three ways:

$$FS_{at}^{t+1} = \begin{cases} FS_{at}^{t} + d_g * G_c * (FS_{ht}^{t} - FS_{at}^{t}) & R_1 \geq Pdp \\ \text{Random Location} & \text{others} \end{cases} \quad (31)$$

d_g is a random distance value for gliding and G_c is a constant value=1.9 used for maintaining balance to the exploration and exploitation states and R_1 is a random value between [0,1]

2-Flying squirrels in normal trees will move to acorn trees, the new position is:

$$FS_{nt}^{t+1} = \begin{cases} FS_{nt}^{t} + d_g * G_c * (FS_{at}^{t} - FS_{nt}^{t}) & R_2 \geq Pdp \\ \text{Random Location} & \text{others} \end{cases} \quad (32)$$

R_2 is a random value between [0,1].

3-Flying squirrels in normal trees may move to hickory trees, and then new position is:

$$FS_{nt}^{t+1} = \begin{cases} FS_{nt}^{t} + d_g * G_c * (FS_{ht}^{t} - FS_{nt}^{t}) & R_3 \geq Pdp \\ \text{Random Location} & \text{others} \end{cases} \quad (33)$$

R_3 also it is random value between [0,1].

The gliding distance and angle can be expressed as in (34):

$$d_g = \frac{h_g}{\tan(\varphi) * sf} \quad (34)$$

$$\tan(\varphi) = \frac{D}{L} \quad (35)$$

$$D = \frac{1}{2\,\rho\,V^2 S\,C_D} \quad (36)$$

$$D = \frac{1}{2\,\rho\,V^2 S\,C_L} \quad (37)$$

Where $h_g = 8$, $sf = 8$, V is the speed, S is the surface area of body, ρ is the density of air, $C_D = 0.6$ and C_L and are constant value between 0.675 and 1.5 then if all individuals have been updated, the season changes is calculated as in (38):

$$S_t^t = \sqrt{\sum_{k=1}^{D} S_{ai,k}^{t} - S_{h,k}^{t}} \quad i = 1,2,\ldots., Nfs \quad (38)$$

At the end of winter season some individuals could not find their food so it must search in other paths, such squirrels will relocate as in (39):

$$f\,S_{inew}^{t+} = Fs_L + Levy(n) * (Fs_U - Fs_L) \quad (39)$$

where $Levy(n)$ is calculated as

$$Levy(n) = 0.01 * \frac{r_a\,\sigma}{|r_b|^{\frac{1}{\beta}}} \quad (40)$$

$$\sigma = \frac{\Gamma\,(1+\beta)\,\sin\left(\frac{\Pi\beta}{2}\right)}{\Gamma\,\frac{1+\beta}{2} * \beta * 2^{\frac{\beta-1}{2}}} \quad (41)$$

$\Gamma(n) = (n-1)!$, β is a constant value=1.5, r_a and r_b are two random values in the range [0,1]. The flowchart of SSA algorithm is indicated in Figure 2. Finally, for achieve an optimal system performance a good choice for the fitness criteria must be utilized [24], different fitness criteria is found like integral of absolute error (ITAE), integral of time square errors (ITSE), integral of square errors (ISE) and integral absolute errors (IAE). In this paper the ITAE in (42) is used as a fitness function [25] for the SSA algorithm to tune the best values for the backstepping controller gains to obtain optimal system response as shown in Figure 3.

$$ITA = \int |e\,|\,dt \quad (42)$$

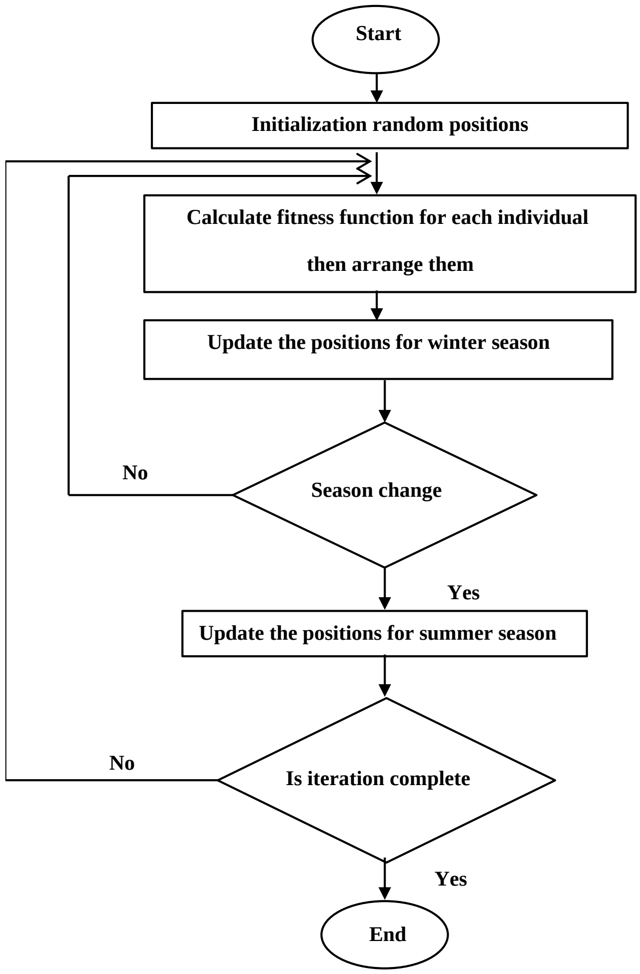

Figure 2. SSA flowchart

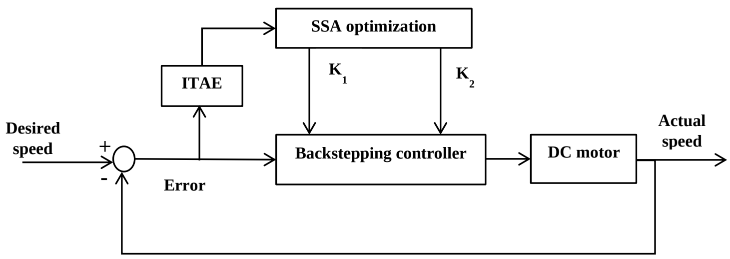

Figure 3. The optimal backstepping controller

5. SIMULATION RESULTS

The optimal backstepping controller is simulated using Matlab/Simulink environment and the parameters values of the DC motor system are given in Table 1 [26]. The SSA tuning algorithm are used for finding the optimal gains of the controller to obtain the desired output for the system and the parameters used for achieve suitable control action by reducing the tracking error with a minimum value of objective function are listed in Table 2.

The ITAE function is considered as a fitness function to test the error continuously [27], the behavior of the ITAE fitness function for the optimal backstepping controller is is shown in Figure. 4. The system response using optimal backstepping controller is shown in Figure 5 and the gain of these two controllers is also tuned using SSA tuning algorithm and shown in Table 3, a comparison with two conventional controllers (PI &PID) is done to show the effectiveness of the proposed controller based on transient response analysis as indicated in Table 4.

Table 2. SSA algorithm parameter

Description	Value
No. of squirrels	30
Maximum number of iteration	50
Density of air	1.204 kg/ m^{-3}
speed	5.25 *m/s*
Surface area of body	154 cm^2
loss in height	8m

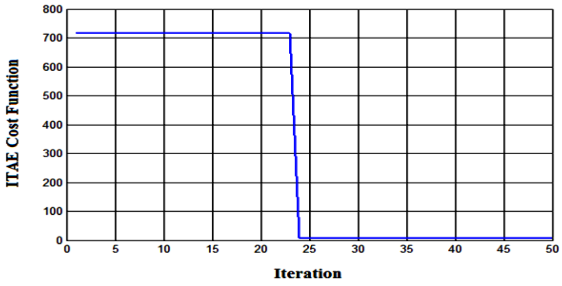

Figure 4. ITAE function for the backstepping controller according to SSA tuning

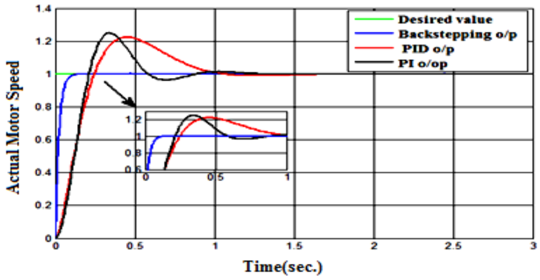

Figure 5. Responses for the three optimal controllers

Table 3. Optimal controllers gains by SSA

Value	Gain	Controller
PI	K_p	55
	K_I	150
PID	K_p	90
	K_I	333
	K_D	9
Backstepping controller	K_1	79.53
	K_2	26.11

From the simulation results, it can be seen that the backstepping controller has a smooth and fast settling time (0.087s) as compared to PI (0.208s) and PID controller (0.238s), that are optimized using the same SSA tuning algorithm, a comparison for these controllers is shown in terms of the main characteristics of response analysis'.

Table 4. Transient response analysis of the optimal three controllers

Controller	Maximum overshoot (%)	Rise time (tr)	Settling time (ts)
PI	0.25	0.16	0.208
PID	0.215	0.125	0.238
Backstepping controller	0	0.052	0.087

It can be seen clearly that the backstepping controller has faster time for reaching to the desired value and without overshoot these criteria are reflected the efficient response of the backstepping controller to track the desired value and save the result with zero error for all the simulation time.

6. COMPARISON ANALYSIS WITH OTHER CONTROLLERS

The performance criteria in table 4 translates the behavior of classical controllers even if optimized with new optimization algorithms, it suffer from small overshoot and have long settling time to reach to desired speed with zero error value as compared with optimal backstepping controller, also a comparative analysis with other controllers tuned by new optimization is done in Table 5 to see the efficient response for the proposed method suggested in this paper.

The response of DC motor for different tuned controllers in Table 5 reflects the efficient response of the proposed controller as compared with conventional one even if it tuned with a new method, the issue is a tradeoff between the stability of the controller represented by the over shoot and the fast response represented by the fast settling time as appeared clearly in the obtained compared values.

Table 5. Transient response comparison for other controllers

Optimization-controller	Overshoot (%)	Rise time (s)	Settling time (s)
SSA-PI	0.25	0.16	0.208
SSA PID	0.215	0.125	0.238
SSA-backstepping controller	0	0.052	0.087
Jaya–PID [7]	2.28	0.1663	0.5214
SFS-PID [8]	0	0.544	1.45
IWO–PID [9]	5.7644	0.1453	0.690
Cuckoo–I-PD [10]	4.2264	0.0841	0.2141
ANFIS-PI [11]	0.609	0.474	0.809
ANFIS-PD [11]	0.562	0.00966	0.0162
ANFIS-PID [11]	2.75	0.587	2.31

7. CONCLUSION

This paper presents an optimal backstepping controller for controlling speed in DC motor based on adopting a new swarm approach called SSA to obtain the optimal parameters and enhance system performance by reducing the error in the steady state analysis, tracking the desired output with less rising time and stable response without any overshoot. Results obtained are compared with the classical controllers (PI &PID) to show the effectiveness of the proposed controller, the proposed controller is faster than PID controller by nearly 41.6% and faster than PI controller by nearly 32% in rise time while in setting time faster than PID controller by nearly 36.97% andthan PI controller by nearly 41.82% also it is more stable than the two classical controllers (PI & PID) as shown in its response. The proposed controller and the smart tuning algorithm together led the system response to its optimal results

REFERENCES

[1] A. Idir, M. Kidouche, Y. Bensafia, K. Khettab and S. A. Tadjer, "Speed Control of DC Motor Using PID and FOPID Controllers Based on Differential Evolution and PSO," *International Journal of Intelligent Engineering and Systems*, vol. 11, no. 4, pp. 241-249, 2018, doi: 10.22266/IJIES2018.0831.24.

[2] B. A. Reddy and D. Sowjanya, "Regulation of A DC Motor Using Second-Order Sliding Mode Strategies," *2019 Third International Conference on Inventive Systems and Control (ICISC)*, 2019, pp. 5-10, doi: 10.1109/ICISC44355.2019.9036427.

[3] L. H. Abood, E. H. Karam and A. H. Issa, "Implementation of Self Tune Single Neuron PID Controller for Depth of Anesthesia by FPGA," In *International Conference on New Trends in Information and Communications Technology Applications*, pp. 159-170, 2018, doi: 10.1007/978-3-030-01653-1_10.

[4] A. A. Sadiq, G. A. Bakare, E. C. Anene and H. B. Mamman, "A fuzzy-based speed control of DC motor using combined armature voltage and field current," *Proceedings of 3rd IFAC International Conference on Intelligent Control and Automation Science*, vol. 46, no. 20, pp. 387-392, 2013, doi: 10.3182/20130902-3-CN-3020.00146.

[5] N. T. Pham, "Novel nonlinear control structure for vector control of SPIM drive using BS PCH," *International Journal of Power Electronics and Drive System*, vol. 11, no. 2, pp. 1099-1108, 2020, doi: 10.11591/IJPEDS.V11.I2.PP1099-1108.

[6] M. Reddak, A. Mesbahi, A. Nouaiti and A. Berdai, "Design and implementation of nonlinear integral backstepping control strategy for single-phase grid-connected VSI," *International Journal of Power Electronics and Drive System*, vol. 10, no. 1, pp. 19-26, 2019, doi: 10.11591/ijpeds.v10.i1.pp19-26.

[7] R. K. Achanta and V. K. Pamula, "DC motor speed control using PID controller tuned by jaya optimization algorithm," *2017 IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI)*, 2017, pp. 983-987, doi: 10.1109/ICPCSI.2017.8391856.

[8] I. Khanam and G. Parmar, "Application of SFS algorithm in control of DC motor and comparative analysis," *2017 4th IEEE Uttar Pradesh Section International Conference on Electrical, Computer and Electronics (UPCON)*, 2017, pp. 256-261, doi: 10.1109/UPCON.2017.8251057.

[9] M. Misaghi and M. Yaghoobi, "Improved invasive weed optimization algorithm (IWO) based on chaos theory for optimal design of PID controller," *Journal of Computational Design and Engineering*, vol. 6, no. 3, pp. 284–295, 2019, doi: 10.1016/J.JCDE.2019.01.001.

[10] D. Puangdownreong, A. Nawikavatan and C. Thammarat, "Optimal Design of I-PD Controller for DC Motor Speed Control System by Cuckoo Search," *Procedia Computer Science*, vol. 86, pp. 83-86, 2016, doi: 10.1016/J.PROCS.2016.05.021.

[11] Y. Guo and M. E. A. Mohamed, "Speed Control of Direct Current Motor Using ANFIS Based Hybrid P-I-D Configuration Controller," in *IEEE Access*, vol. 8, pp. 125638-125647, 2020, doi: 10.1109/ACCESS.2020.3007615.

[12] G. K. Rajput *et al*., "Design of TID controller based on firefly algorithm for controlling the speed of a DC Motor," *E3S Web of Conferences-2nd International Conference on Design and Manufacturing Aspects for Sustainable Energy (ICMED 2020)*, vol. 184, p. 01038, 2020, doi: 10.1051/e3sconf/202018401038.

[13] B. Hekimoğlu, "Optimal Tuning of Fractional Order PID Controller for DC Motor Speed Control via Chaotic Atom Search Optimization Algorithm," in *IEEE Access*, vol. 7, pp. 38100-38114, 2019, doi: 10.1109/ACCESS.2019.2905961.

[14] H. Chaudhary, S. Khatoon and R. Singh, "ANFIS based speed control of DC motor," *2016 Second International Innovative Applications of Computational Intelligence on Power, Energy and Controls with their Impact on Humanity (CIPECH)*, 2016, pp. 63-67, doi: 10.1109/CIPECH.2016.7918738.

[15] M. A. Ibrahim, A. N. Hamoodi and B. M. Salih, "PI controller for DC motor speed realized with Simulink and practical measurements," *International Journal of Power Electronics and Drive System*, vol. 11, no. 1, pp. 119-126, 2020, doi: 10.11591/ijpeds.v11.i1.pp119-126.

[16] O. Mahmoudi and A. Boucheta, "Adaptive integral backstepping controller for linear induction motors," *International Journal of Power Electronics and Drive System*, vol. 10, no. 2, pp. 709-719, 2019, doi:10.11591/IJPEDS.V10.I2.PP709-719.

[17] J. Zhao, D. Song, B. Zhu, Z. Chen and Y. Sun, "Nonlinear Backstepping Control of Electro-Hydraulic Brake System Based on

Bond Graph Model," in *IEEE Access*, vol. 8, pp. 19100-19112, 2020, doi: 10.1109/ACCESS.2020.2968513.

[18] M. A. M. Basri, K. A. Danapalasingam, and A. R. Husain, "Design and optimization of backstepping controller for an under actuated autonomous quad rotor unmanned aerial vehicle," *Transactions of Famena*, vol. 38, no. 3, pp. 27–44, 2014, doi: 10.1007/S11071-016-2655-Y.

[19] A. Mechter, K. Kemih and M. Ghanes, "Backstepping control of wind turbine for low wind speeds," *Nonlinear Dynamics, Springer*, vol. 84, no. 4, pp. 2435-2445, 2016, doi: 10.1007/s11071-016-2655-y.

[20] M. Jain, V. Singh and A. Rani, "A novel nature-inspired algorithm for optimization: Squirrel search algorithm," *Swarm and Evolutionary Computation*, vol. 44, pp. 148-175, 2019, doi: 10.1016/j.swevo.2018.02.013

[21] M. Suman, V. P. Sakthivel and P. D. Sathya, "Squirrel Search Optimizer: Nature Inspired Metaheuristic Strategy for Solving Disparate Economic Dispatch Problems," *International Journal of Intelligent Engineering and Systems*, vol. 13, no. 5, pp. 111-121, 2020, doi: 10.22266/ijies2020.1031.11.

[22] H. Hu, L. Zhang, Y. Bai, P. Wang and X. Tan, "A Hybrid Algorithm Based on Squirrel Search Algorithm and Invasive Weed Optimization for Optimization," in *IEEE Access*, vol. 7, pp. 105652-105668, 2019, doi: 10.1109/ACCESS.2019.2932198.

[23] N. A. Al-Saati, and Z. Y. Algamal, "A modified squirrel search algorithm for solving facility layout problems," *Telecommunication Computing Electronics and Control (TELKOMNIKA)*, vol. 20. no. 2, pp. 348-356, 2022, doi: 10.12928/telkomnika.v20i2.21845.

[24] L. H. Abood, and B. K. Oleiwi, "Design of fractional order PID controller for AVR system using whale optimization algorithm," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 23, no. 3, pp. 1410-1418. 2021, doi: 10.11591/ijeecs.v23.i3.pp1410-1418.

[25] L. H. Abood, E. H. Karam and A. H. Issa, "FPGA Implementation of Single Neuron PID Controller for Depth of Anesthesia Based on PSO," *2018 Third Scientific Conference of Electrical Engineering (SCEE)*, 2018, pp. 247-252, doi: 10.1109/SCEE.2018.8684186.

[26] F. S. M. Alkhafaji, W. Z. W Hasan, M. M. Isa and N. Sulaiman, "A response time reduction for DC motor controller using SISO technique," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 17, no. 2, pp. 895-906, 2020, doi: 10.11591/IJEECS.V17.I2.PP895-906.

[27] M. I. Berbek and A. A. Oglah, "Adaptive neuro-fuzzy controller trained by genetic-particle swarm for active queue management in Internet congestion," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 26, no. 1, pp. 229–242, 2022, doi: 0.11591/ijeecs.v26.i1.pp229-242.

BIOGRAPHIES OF AUTHORS

Layla H. Abood received her B.Eng. and M.Sc. and PHD degrees in Electronic and Communication Engineering from the University of Technology- Baghdad. She is currently an Academic staff member in the Department of Control and System Engineering, University of Technology, Baghdad, Iraq. Her research interests are artificial intelligent, control systems, system modeling, optimization techniques, IoT, image processing, robotics, microcontrollers, fpga and embedded systems. She can be contact at email: 60066@uotechnology.edu.iq.

Bashra Kadhim Oleiwi Chabor Alwawi born in Baghdad-Iraq completed a Master degree in Mechatronics Engineering/ Control and Systems Engineering Department at University of Technology (UOT) Bagdad-Iraq. She finished her PhD degree at Control Engineering Department (RST), Siegen University, Germany. She is currently working as a faculty member in control and systems engineering department at UOT. Her research interests are deep learning, machine learning, artificial intelligence systems, IoT, optimization, image processing, robotics, path planning, automation, control, microcontrollers and sensors. She can be contact at email: bushra.k.oleiwi@uotechnology.edu.iq.
.

Ekbal Hussain Ali received BS.c, M.S.c, PhD. Degrees in Electrical Engineering from Electromechanical Engineering Department (previously namedTechnological Education Department) in 1995, 2001, and 2006, respectively, University of Technology, Baghdad; Iraq.She is currently an Academic staff member in the Department of Electromechanical Engineering Department. University of Technology, Baghdad, Iraq. her research interests are navigation systems, communication, artificial intelligent, control systems, system modeling, image processing. She can be contact at email: ekbal.h.ali@uotechnology.edu.iq.